Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	)	
Use of Spectrum Bands Above 24 GHz For Mobile Radio Services	)	GN Docket No. 14-177
Establishing a More Flexible Framework to Facilitate Satellite Operations in the 27.5-28.35 GHz and 37.5-40 GHz Bands	)	IB Docket No. 15-256
Petition for Rulemaking of the Fixed Wireless Communications Coalition to Create Service Rules for the 42-43.5 GHz Band	)	RM-11664
Amendment of Parts 1, 22, 24, 27, 74, 80, 90, 95, and 101 To Establish Uniform License Renewal, Discontinuance of Operation, and Geographic Partitioning and Spectrum Disaggregation Rules and Policies for Certain Wireless Radio Services	)	WT Docket No. 10-112
	)	IB Docket No. 97-95
Allocation and Designation of Spectrum for Fixed-Satellite Services in the 37.5-38.5 GHz, 40.5-41.5 GHz and 48.2-50.2 GHz Frequency Bands; Allocation of Spectrum to Upgrade Fixed and Mobile Allocations in the 40.5-42.5 GHz Frequency Band; Allocation of Spectrum in the 46.9-47.0 GHz Frequency Band for Wireless Services; and Allocation of Spectrum in the 37.0-38.0 GHz and 40.0-40.5 GHz for Government Operations	)	

COMMENTS OF THE NATIONAL ACADEMY OF SCIENCES' COMMITTEE ON RADIO FREQUENCIES

The National Academy of Sciences through its Committee on Radio Frequencies (hereinafter, CORF[1]), hereby submits its comments in response to the Commission's October 23, 2015, *Notice of Proposed Rulemaking* (*NPRM*) in the above-captioned

[1] See the Appendix for the membership of the Committee on Radio Frequencies.

dockets. In these Comments, CORF discusses the importance of passive observations by users of the Radio Astronomy Service (RAS) and the Earth Exploration Satellite Service (EESS) in some of the frequency bands discussed in the *NPRM*, and protection of such observations. CORF generally supports the sharing of frequency allocations where practical, but in this rulemaking, protection of passive scientific observation must be addressed.

I. Introduction: The Role of Radio Astronomy and Earth Remote Sensing, and the Vulnerability of Passive Services to Interference.

CORF has a substantial interest in this proceeding, as it represents the interests of the passive scientific users of the radio spectrum, including users of the RAS and EESS bands. These users perform extremely important, yet vulnerable, research. Furthermore, extensive experience in operating instruments above 24 GHz makes this community well suited to comment on technical matters in this frequency range.

As the Commission has also long recognized, radio astronomy is a vitally important tool used by scientists to study our universe. It was through the use of radio astronomy that scientists discovered the first planets outside the solar system, circling a distant pulsar. The discovery of pulsars by radio astronomers has led to the recognition of a widespread galactic population of rapidly spinning neutron stars with gravitational fields at their surface up to 100 billion times stronger than on Earth’s surface. Subsequent radio observations of pulsars have revolutionized understanding of the physics of neutron stars and have resulted in the only experimental evidence so far for gravitational radiation. Radio astronomy has also enabled the discovery of organic matter and prebiotic molecules outside our solar system, leading to new insights into the potential existence of life elsewhere in our galaxy, the Milky Way. Radio spectroscopy and broadband continuum observations have identified and characterized the birth sites of stars in the Milky Way galaxy, the processes by which stars slowly die, and the complex distribution and evolution of other galaxies in the universe. The enormous energies contained in the enigmatic quasars and radio galaxies discovered by radio astronomers have led to the recognition that most galaxies, including the Milky Way, contain supermassive black holes at their centers, a phenomenon that appears to be crucial to the creation and evolution of galaxies. Synchronized observations using widely spaced radio telescopes around the world give extraordinarily high angular resolution, far superior to that which can be obtained using the largest optical telescopes on the ground or in space.

Radio astronomy measurements led to the discovery of cosmic microwave background (CMB), the radiation left over from the original Big Bang, which has now cooled to only 2.7 K above absolute zero. Later observations revealed weak temperature fluctuations in the CMB of only one-thousandth of a percent—signatures of tiny density fluctuations in the early universe that were the seeds of the stars and galaxies we know today. Within our own solar system, radio astronomy observations of the Sun have been used for more than half a century to aid in the prediction of terrestrial high-frequency radio propagation.

Since 1974, eight scientists, six of whom are American, have received the Nobel Prize in physics for their work in radio astronomy.

The critical science undertaken by RAS observers, however, cannot be performed without access to interference-free bands. Notably, the emissions that radio astronomers receive are extremely weak—a radio telescope receives less than 1 percent of one-billionth of one-billionth of a watt (10^{-20} W) from a typical cosmic object. Because radio astronomy receivers are designed to pick up such remarkably weak signals, radio observatories are particularly vulnerable to interference from in-band emissions, spurious and out-of-band emissions from licensed and unlicensed users of neighboring bands, and emissions that produce harmonic signals in the RAS bands, even if those man-made emissions are weak and distant.

The Commission has also long recognized that satellite-based Earth remote sensing, including sensing by users of the EESS bands, is a critical and uniquely valuable resource for monitoring aspects of the global atmosphere, land, and oceans. For certain applications, satellite-based microwave remote sensing represents the only practical method of obtaining atmospheric and surface data for the entire planet. EESS data have contributed substantially to the study of meteorology, atmospheric chemistry, climatology, and oceanography. Currently, instruments operating in the EESS bands provide regular and reliable quantitative atmospheric, oceanic, and land measurements to support a broad variety of scientific, commercial, and government (civil and military) data users. U.S. EESS satellites represent billions of dollars in investment and provide data for major governmental users, including the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation, the National Aeronautics and Space Administration (NASA), the Department of Defense (DoD, especially the U.S. Navy), the Department of Agriculture, the U.S. Geological Survey, the Agency for International Development, the Federal Emergency Management Agency, and the U.S. Forest Service. These agencies use EESS data on issues impacting hundreds of billions of dollars in the U.S. economy.

As a general technical note applicable to all proposed new frequency allocations, care must be taken in assessment of the impact on incumbent EESS bands. While RAS bands can be protected regionally by limiting emissions within a certain radius of a facility, this is not the case with EESS observations, which are typically satellite-based and global in extent. The only technique conceivable to protect these observations is time sharing of the band; e.g., dynamic scheduling to accommodate frequent passes overhead. This is of particular interest given the choice of frequencies proposed by the Commission. In the case of three of the selected bands (31.0-31.3, 37.0-38.6, and 81-86 GHz), comments are sought on proposed operations immediately adjacent to passive remote sensing bands, with no guard-band protection. This is critically important because the incumbent users of these bands designed and developed EESS missions without the expectation of transmissions in such close spectral proximity. Indeed, most incumbent passive users at 31.5 and 37 GHz operate in a direct detection (homodyne) mode. Until such time that current satellites can be replaced with satellites with filtering suited to the new spectral environment, CORF recommends protection of these vital orbital assets through provision of adequate guard bands.

In direct detection, band definition is achieved with filters that are limited by the properties of the materials used in the filter itself. For a given material, the minimum bandwidth of a filter is proportional to the central frequency, so the width of the necessary guard bands to suppress emissions to a desired level also increases in proportion to the frequency. In other words, proportionally larger guard bandwidths are needed as the frequency increases. It is impossible to reject a signal 10 MHz away from a band edge at these higher frequencies, so guard bandwidths must be scaled in frequency to accommodate this physical limitation. Furthermore, for the same reasons, it is likely that mobile devices with limited size and cost will not be able to adequately filter their out-of-band (OOB) emissions to meet the stringent requirements of these passive bands.

In sum, the important science performed by radio astronomers and Earth remote sensing scientists cannot be performed without access to interference-free bands. Loss of such access constitutes a loss for the scientific and cultural heritage of all people, as well as a loss of the practical applications enabled by this access, which can include financial loss arising from impaired weather forecasting and climate monitoring.

II. Passive Use and Protection of Specific Frequency Bands.

The *NPRM's* proposals for certain specific bands are discussed below.

A. 37.0-38.6 GHz.

1. EESS.

At Paragraph 53, the *NPRM* acknowledges that the Commission "will have to address … ensuring protection of [EESS] passive operations below 37 GHz." Surprisingly, at Para. 176 the *NPRM* seeks comments "whether any special protections are necessary or appropriate for passive services below 37 GHz." CORF believes that the record regarding the nature and importance of remote sensing operations at 36-37 GHz demonstrates that such protections are indeed necessary and appropriate.

The primary EESS allocation at 36-37 GHz is used by instruments on behalf of many federal agencies. In particular, this band has applications in global weather forecasting and ocean surface topography, ocean winds, and sea ice. The band offers the largest contiguous bandwidth for passive observations between the 23 GHz water line and the 60 GHz oxygen line complex. Because this bandwidth affords unmatched radiometric sensitivity, applications are found in a range of environmental conditions, including atmospheric water vapor, precipitation, cloud properties, freeze/thaw conditions, snow, sea ice, sea-surface temperature, ocean vector winds, and ocean topography (tracing conditions such as El Niño). With such a wide range of applications, it is not surprising that this band is of great importance to weather forecasting. NASA, DoD, and NOAA have extensive investments in satellite instruments that include observations from 36-37 GHz. These include the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave Imager (SSMI) and SSMI/Sounder (SSMI/S) instruments operating on four separate satellites; DoD's WindSat mission (DoD weather instruments operate with a center frequency of 37 GHz); NASA's Global Precipitation Measurement Mission (GPM) Microwave Imager (GMI); and international instruments that contribute to U.S. forecast capabilities, including the Advanced Microwave Scanning Radiometer 2 (AMSR-2) on Japan's GCOM-W1 satellite.[2] These missions represent a combined investment of more than $1 billion, with EESS data critical to activities impacting hundreds of billions of dollars in the U.S. economy.

While this observation band is co-primary with Fixed and Mobile services as well as Space Research passive services, this EESS co-existence has been benign, largely due to limited active use of this band. Widespread use would likely change this situation.

---

[2] It should also be noted that the DoD sensors operate at 37±0.5 GHz. The 37-37.5 GHz band poses a problem because it is CORF's understanding that the existing weather satellites operating in this band are expected to continue operating through at least 2020. It is CORF's recommendation that the Commission coordinate the roll-out of any new 37-37.5 GHz regulations with the DoD sponsor of these assets.

The following detailed analysis for GMI, which views the ground directly with a 48.5° scan angle, is provided as an example. The expected signal level per transmitter can be found from the Friis equation

$$P_R = \frac{P_T G_T A_{eff} e^{-\tau}}{4\pi R^2},$$

where P_R = power received, P_T = power transmitted, A_{eff} = effective area of receive antenna, and τ = atmospheric opacity.

For GMI, $A_{eff} \approx 0.3\ m^2$, with an altitude of 403 km, the range R ≈ 648 km, and the path loss for typical sea- level opacity at 53° zenith angle is -2 dB. So for a single 1 watt (W) transmitter with a dipole antenna, the received power is 8.5×10^{-14} W, or -101 dBm (-131 dBW). The GMI sensitivity (or measurement uncertainty) is specified as (Draper et al. 2015) [3]

$$\Delta T = 0.42K.$$

Converting to a noise equivalent power,

$$\Delta P = k_B \Delta T \beta,$$

where k_B = Boltzmann constant (1.38×10^{-23} W/K-Hz), β = receiver bandwidth, and 1000 MHz for GMI. A receiver noise level of

$$\Delta P = 5.8 \times 10^{-15} W = -112.4\ dBm$$

is derived, which is 11.4 dB below the interfering signal level. For GMI and the other instruments operating at 36.5 GHz, a 1% signal contamination, with minimal impact on the measurements would require ~32 dB signal attenuation. For comparison, ITU

---

[3] Draper, D.W.; Newell, D.A.; Wentz, F.J.; Krimchansky, S.; Skofronick-Jackson, G.M., "The Global Precipitation Measurement (GPM) Microwave Imager (GMI): Instrument Overview and Early On-Orbit Performance," IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 8(7):3452-3462, July 2015, doi: 10.1109/JSTARS.2015.2403303.

RS.2017 recommends a maximum interference level of -166 dBW, which would require an attenuation of 35 dB. This analysis assumes a single 1 W transmitter in the field of view (footprint of the sensor beam). For unlicensed mobile operations, it is unknown how many emitters exist in a single 8.6 km x 14.4 km footprint of the sensor. The aggregate emitted power level within a footprint can be used as P_T in the analysis above to estimate interference levels.

The DoD SSMI/S instruments have similar noise characteristics to GMI but operate with a somewhat smaller antenna and at an altitude of 833 km and with a bandwidth of 1600 MHz centered at 37 GHz. The same source described above would interfere with an SSMI/S at a level of -112 dBm. So, in direct response to the question posed in the *NPRM*, a 100 MHz guard band will not be sufficient to protect the DoD SSMI or SSMI/S instruments from widespread transmissions in the 37-37.5 GHz range.

While the older instruments operating in this band operate with higher noise heterodyne receivers, modern instruments employ a low-noise, low-power, amplified, direct-detection receiver architecture (requiring stricter -166 dBW prescription of RS.2017). In this scenario, the bandpass shape of the instrument is determined by filters at the radio frequency (RF). There are physical limitations, based on materials properties, to the rejection of signals from nearby frequencies. While it is possible for future sensors to reduce the operating bandwidth, such reduction comes with a decrease in sensitivity and an associated loss in weather forecast skill. The current suite of instruments operating at 36.5 GHz have bandpass filters with 3 dB rejection at 36.98 GHz and 41 dB rejection at 37.1 GHz. Even though a 100 MHz guard band provides adequate protection against interference from a single 1 W emitter, in the real world, signals from multiple emitters would result in aggregate interference that may require a wider guard band.

It should also be noted that similar band rejection limitations exist for mobile transmitters that would operate in adjacent bands, making their ability to meet OOB emissions requirements very challenging. It is difficult to assess what rejection developers might achieve without knowing the specific application, but as a general rule of thumb, better filtering requires larger components, which tend to introduce loss at higher frequencies and are, therefore, shunned by handset developers. The same -166 dBW criterion should be applied for OOB emission into the protected 36-37 GHz band.

The 37-37.5 GHz band poses a problem because the existing DoD weather satellites using this band are expected to continue operating through at least 2020. It is CORF's recommendation that the Commission coordinate the roll-out of 37-37.5 GHz regulations with the DoD sponsor of these assets.

Finally, it is also noteworthy that while EESS applications directly view Earth and are particularly susceptible to radio frequency interference (RFI), the satellites are overhead for very short periods of time (typically 10 minutes per day for each satellite). This naturally lends itself to a technologically enforced timesharing arrangement, where transmissions in sensitive bands are ceased during observations overhead and resume 2 minutes later. This complex process would require, however, that handsets and base stations have knowledge of the ephemerides of the affected satellites.

2. RAS.

As noted in Para. 173 of the *NPRM*, the 36.43-36.5 GHz band is used for radio astronomy spectral line emissions and is subject to protection from interference pursuant to footnote US342. Observation at this band in the United States occurs primarily at the Green Bank Telescope (West Virginia), the Very Large Array (Socorro, New Mexico), and the Owens Valley Radio Observatory (California). Research in this band is important for the observation of methanol, which plays a significant role in the chemistry of circumstellar envelopes of late-type stars, and research into star formation. This band is also used for continuum observations and for observation of redshifted lines from distant galaxies, which trace the history of the universe and the formation of galaxies.

CORF recommends protection of these limited RAS sites based on terrain shielding from the curvature of Earth. Thus, operation of mobile units and any unlicensed fixed transmitters should be prohibited within 30 km of the above RAS sites. Licensed fixed transmitters should be required to coordinate any operations that are either within 30 km of the three sites, or that are at a greater distance but still in the line-of-site (LOS) to the RAS observatory due to the altitude of the transmitter.[4] The Commission should place limits on spurious emissions and/or define exclusion (or coordination) zones to meet ITU RA.769, taking into account the possibility of aggregate interference from multiple transmitters.

B. 64-71 GHz.

1. EESS.

The EESS has a co-primary allocation at 65-66 GHz. However, in light of the Commission's proposal to unify rules at 64-71 GHz with those for 57-64 GHz, the primary concern for remote sensing scientists here is the 57-59.3 GHz sub-band, which

[4] In addition, operators are required to comply with the provisions of Section 1.924(a) of the Commission's rules regarding the National Radio Quiet Zone.

is vitally important to weather forecasting. Instruments observing in this band include NASA/NOAA's Advanced Technology Microwave Sounder (ATMS),[5] their Advanced Microwave Sounding Unit (AMSU-A),[6] and the DoD's SSMI/S.[7] Virtually all weather forecast models utilize atmospheric temperature data derived from this band to initialize the models. Recent analysis has shown that the microwave temperature data from the AMSU-A is responsible for 17% of weather forecast accuracy, the largest single factor.[8] Because of this, CORF strongly urges the Commission to use great caution before authorizing aeronautical transmissions at 57-59.3 GHz.

It is important to understand that low-power terrestrial use of this band has little impact on satellite observations. Observations between 50 and 60 GHz use the atmospheric oxygen absorption line complex from 57-61 GHz. By making observations on and off of the 57-61 GHz absorption band, the atmospheric temperature as a function of altitude is obtained. As observations move closer to the absorption line complex, the atmosphere becomes more opaque and signals do not travel as great a distance. As altitude is increased, oxygen pressure decreases and the absorption adjacent to the line complex weakens. Accordingly, satellite observations made near the line complex trace the temperature at higher altitudes. This also means that emissions from low altitudes are much more greatly attenuated than those from high altitudes (see Fig. 1, below). For terrestrial applications, the attenuation is so great that there is no reasonable impact from mobile or fixed transmissions. However, airborne applications

---

5 *See,* http://www.jpss.noaa.gov/atms.html.

6 *See,* http://disc.sci.gsfc.nasa.gov/AIRS/documentation/amsu_instrument_guide.shtml.

7 *See,* https://nsidc.org/data/docs/daac/ssmis_instrument/ and http://mirs.nesdis.noaa.gov/ssmis.php.

8 *See,* European Centre for Medium Range Weather Forecasts' weather forecast model, reprinted in "Earth Science and Applications from Space: A Midterm Assessment of NASA's Implementation of the Decadal Survey," at page 20, National Academies Press (2012), ISBN 978-0-309-25702-2.

are a completely different matter. CORF follows the same analysis set out above for the GMI at 37 GHz, but applies it here to the NASA/NOAA ATMS instrument at 57 GHz. ATMS observes a range of angles ranging from 0°- 45°, with the nadir view 0° representing the worst case. ATMS has an antenna FWHM (Full width at half maximum) of 2.2° (or 38 dB gain), an orbital altitude of 824 km, a bandwidth of 330 MHz, and $\Delta T = 0.42K$.[9] For aircraft at 30,000 feet, $e^{-\tau}$ is -33 dB, while at 40,000 feet it is only -13 dB at 57 GHz. So, for a 1 W transmitter with a dipole radiator in-band, at 30,000 feet, the ATMS would receive -149 dBm against a noise of -117 dBm for a LOS margin of 32 dB for unity signal-to-noise ratio. However, at 40,000 feet, ATMS will receive -129 dBm with a margin of only 12.5 dB.

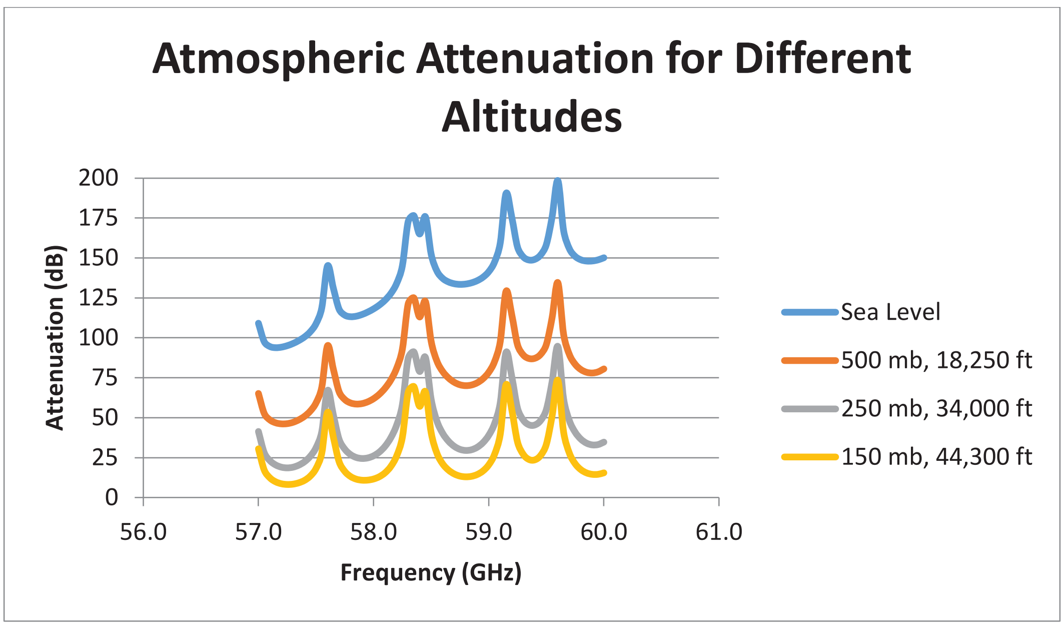

Figure 1. Atmospheric attenuation versus frequency for four different altitudes. (Data obtained using AM model - Harvard-Smithsonian Center for Astrophysics.)

9 *See,* Kim, E., C.-H.J. Lyu, K. Anderson, R.V. Leslie, and W.J. Blackwell, "S-NPP ATMS Instrument Prelaunch and On-Orbit Performance Evaluation," Journal of Geophysical Research: Atmospheres, 119(9):5653-5670, May 19, 2014.

CORF's assumptions in this analysis are somewhat tentative. The transmission power may be less than 1 W; it is unlikely there often will be a direct LOS from the transmitter to the satellite; and the WiGig devices proposed for airborne use have a standard 2 GHz of bandwidth. On the other hand, there could be a large but unknown number of radiators (computers) on any given aircraft, and accordingly, with widespread use of this new WiFi standard, one cannot readily predict how much additional power will be emitted from computer-to-computer transmissions inside the aircraft (in addition to the transmissions from aircraft access points to computers).

CORF is similarly concerned that in investigating potential interference, it was unable to find any peer-reviewed studies that characterize aircraft interior-exterior attenuation at these frequencies. Additional concerns are raised because there are few places within an aircraft to transmit a direct LOS signal to a laptop located in the aircraft. This means that transmission/access points will likely bounce signals off of the walls of the aircraft (or even the somewhat reflective windows) -- potentially spraying RF power with high antenna gain much higher than 3 dB directly out of the aircraft. CORF notes, however, that RF reflective window films exist and could be installed at very low cost to the aircraft manufacturers.

Given that the remote sensing measurements at 57-59.3 GHz are vital to weather forecasting and thus the national interest, and that they cannot be moved to another frequency, CORF makes the following recommendations: 1) Peer-reviewed studies should be performed to better assess real-world transmission scenarios in aircraft prior to authorizing unlicensed airborne use of this band; 2) Aircraft operators should retain responsibility for ensuring RF leakage levels are below threshold levels

(-166 dBW at the satellite) through licensing of airborne operations in this band; and 3) in the absence of better data, airborne use of WiGig Channel 1 (57.24-59.4 GHz) should be prohibited, while allowing transmission on the remaining WiGig channels. This should be easy to implement in the form of an "Airplane Mode" for WiGig -- exactly as already exists today for the LTE (Long-Term Evolution) bands.

2. RAS.

While RAS does not have allocations at the 64-71 GHz Band, it does have co-primary allocations at the first and second harmonics of this band, at 128-142 GHz and at 192-213 GHz.[10] These harmonic bands are subject to protection due to allocations for RAS, as well as pursuant to Footnote US342.[11] Observations at these frequencies are of atomic and molecular emission from our galaxy and galaxies throughout the history of the universe. Lines of carbon monoxide, carbon, nitrogen, and oxygen allow us to study very high-redshift sources from the reionization epoch, possibly enabling us to study the first galaxies. Lines from molecules such as HCN, HCO+, SiO, CO, and H_2O allow us to study the structure and energetics of galaxies, star formation, and the gas flows associated with supermassive black holes at the centers of galaxies. In our own galaxy, we can study the chemistry of the interstellar medium and the formation of complex organic molecules, which are possibly the building blocks for life, and the formation of planets around other stars.[12]

---

[10] The RAS has only a secondary allocation at 134-136 GHz.

[11] *Cf.* Para. 305 of the *NPRM*, noting that in connection with development of the 57-64 GHz band, that "[h]armonics could also interfere with radio astronomy operations at the 111.8-114.25 GHz, 217-226 GHz, and 241-248 GHz bands." Footnote US342 also protects passive observations at 151.5-158.5, 168.59-168.93, 171.11-171.45, 172.31-172.65, 173.52-173.85, 195.75-196.15, 209-226, and 241-250 GHz.

[12] For example, lines at 137.45, 140.840, and 146.969 GHz are listed as among those of greatest importance to radio astronomy. *See*, Handbook on Radio Astronomy, (ITU Radiocommunications

The primary sites for RAS observation in these bands in the United States are Mt. Graham and Kitt Peak in Arizona and Mauna Kea in Hawaii. The benchmark value for interference for these bands (-204 dBW/m^2/Hz) is taken from Col. 9 of Table 2 of ITU RA.769-2 for spectral lines. The Commission should limit spurious emissions from transmitters in this band. All of the observatories observing in these bands are on very high, dry sites with a LOS horizon of hundreds of kilometers. Because of the high observatory locations, there is little if any protection from terrain shielding. Protection from unwanted emissions is obtained primarily from the inverse square law, combined with atmospheric attenuation, which is about 0.5 dB/km at these frequencies. If spurious emission is permitted at a level as high as 0 dBm/MHz, then a single unlicensed device closer than 28 km would exceed the RA.769 threshold. If a single device is as close as 1 km, then the spurious limit must be below -73 dBW/MHz. If there are multiple devices, then either the protection radius must be increased or the levels of spurious emission must be correspondingly reduced. The same limits and radii apply to spurious emissions from devices aboard aircraft.[13] The Commission should place limits on spurious emission and/or define exclusion (or coordination) zones to meet RA.769, taking into account the possibility of aggregate interference from multiple transmitters.

C. <u>70/80 GHz Bands (71-76 GHz, 81-86 GHz).</u>

There are primary allocations to RAS at 76.0-77.5 GHz and 78.0-94 GHz. These bands are used very extensively for a wide range of continuum and spectral line

---

Bureau, 2013) at Table 3.2. In addition, Table 3.1 of the <u>ITU Handbook</u> lists 123-158.5, 164-167, 200-231.5, 241-248, and 250-275 GHz as among the frequency bands preferred for continuum observations.

[13] These limits do not address the problem of aggregate interference.

observing. Because there is relatively little absorption from atmospheric O_2 and H_2O, these bands constitute some of the most important high-frequency ranges for both continuum and line observations of celestial objects.[14] The U.S. radio astronomy community has been a leader in millimeter-wavelength research, with the initial discovery of a very wide range of complex molecules in space. The understanding of star formation and evolution is critically dependent on millimeter-wave observations. Highly redshifted galaxies can be detected over the full range of the RAS allocations. It is essential that the protection presently available remain in place.

The 86-92 GHz band is also a primary allocation to EESS. This band is used by the satellite based instruments such as the NOAA AMSU-A, AMSU-B, and ATMS, the DoD's SSMI and SSMI/S, as well as the AMSR-2 instruments. The primary data product is precipitation (from cloud ice scattering), and it is widely used to provide real-time imagery for weather forecasting (similar to NOAA's NexRad system).[15] The band usage tends to be quite broad in order to reduce the effect of the higher receiver noise at these frequencies. As such, this band is also highly susceptible to OOB emissions and, being at a higher frequency and having a large bandwidth would require even wider guard bands.

1. RAS.

---

[14] For example, lines at 80.578, 85.339, 86.243, and 86.754 GHz are listed as among those of greatest importance to radio astronomy. *See*, Handbook on Radio Astronomy, *supra* note 11, at Table 3.2. In addition, Table 3.1 of the ITU Handbook lists 76-116 GHz as among the frequency bands preferred for continuum observations.

[15] *See,* http://www.srh.noaa.gov/srh/sod/radar/radinfo/radinfo.html.

The primary U.S. sites where RAS observations are made in this band are located at Mt. Graham, as well as Kitt Peak, Arizona, and Mauna Kea, Hawaii, and the eight other sites in the Very Long Baseline Array.[16]

In regards to protection of RAS at 71-76 GHz and 81-86 GHz from proposed unlicensed usage, the interference level (-204 dBW/m^2/Hz) in Col. 9 of Table 2 in ITU-R RA.769-2 results in a limit in transmitted power of -77 dBW/MHz, or -77 dBW EIRP (Equivalent Isotropically Radiated Power) transmitted power if the device is as close as 1 km to an observatory. If devices are restricted from being used at a greater distance from the observatory, then the limit of transmitted power would be correspondingly increased. Note that all the observatories concerned are at very high, dry sites, so that little if any terrain shielding is in effect. The signal attenuation with distance is due only to the inverse square law, with some small atmospheric attenuation.

Footnote US342 requires protection of RAS observation at 76-86 GHz. Thus, in considering unlicensed usage, the Commission would also have to limit spurious emissions from unlicensed transmitters in these bands. The nature of the emission mask depends on how close the unlicensed devices are to the observatory. If that distance is 28 km, then an aggregate limit of 0 dBm/MHz would suffice. If the distance is 1 km, then the aggregate limit must be below -43 dBm/MHz.[17]

2. EESS.

At issue for EESS for this proposed rulemaking are possible spurious emissions. Section 15.255(c) restricts spurious emissions to a power density limit of 90 pW/cm^2 at a distance of 3 m for frequencies between 40 and 200 GHz. An analysis is provided

[16] Other U.S. facilities may observe in this band in the future.
[17] These limits do not address the problem of aggregate interference.

below to evaluate the use of this limit for the 71-76 GHz and 81-86 GHz bands. As an example, GMI is used. GMI views Earth with a 1.2 m diameter antenna at approximately a 50-degree angle from an orbit altitude of approximately 400 km. The atmospheric transmittance (Earth-to-space) at this viewing geometry is approximately 0.75 at 92 GHz for the US 1976 standard atmosphere.

First note that a power density (P_d) of 90 pW/cm^2 at 3 m is equivalent to an EIRP of -10 dBm (EIRP = P_d*4πr^2). Using the Friis equation to calculate the power incident to the GMI receiver (at a LOS distance of approximately 650 km) for a single transmitter transmitting -10 dBm with a dipole antenna, the power into the receiver is -169 dBW, less than the ITU-RS.2017 recommended limit of -166 dBW.

CORF further notes that multiple simultaneous transmitters in any 7 km diameter GMI footprint (for the 89 GHz channels) at the -10 dBm limit would likely violate the -166 dBW ITU limit. This renders the proposed usage incompatible with protection of EESS observation.

III. Summary.

In this filing, CORF makes the following principal recommendations regarding the given frequency bands:

A) 37.0-38.6 GHz: CORF recommends that the FCC consider a guard band greater than 100 MHz due to the concern of aggregate interference by multiple emitters in this critical EESS band. CORF also recommends protection of three RAS sites by excluding unlicensed devices operating in this band within 30 kilometers, and by exclusion or coordination of licensed fixed transmitters within 30 kilometers or line-of-sight to the RAS observatory. (pp. 6-11)

B) 64-71 GHz: In light of the proposal to unify rules in this band with those for operations at 57-64 GHz, CORF notes that the 57-59.3 GHz sub-band is vitally important for weather forecasting and cannot be moved to another frequency. CORF strongly urges the Commission to use great caution before authorizing aeronautical transmissions at 57-59.3 GHz. First, peer-reviewed studies should be performed to better assess real-world transmission scenarios in aircraft prior to authorizing unlicensed airborne use of this band. Second, aircraft operators should retain responsibility for ensuring RF leakage levels are below threshold levels if aeronautical operations are permitted. Third, in the absence of better data, airborne use of WiGig Channel 1 (57.24-59.4 GHz) should be prohibited. CORF also notes that unwanted and spurious emissions of the second and third harmonics of 64-71 GHz are a concern for RAS facilities, and recommends placing emission limits and/or defining exclusion (or coordination) zones, accounting for aggregate interference from multiple transmitters. (pp.11-16)

C) 71-76 GHz and 81-86 GHz: It is essential that the protections presently available to the primary allocations to RAS at 76.0-77.5 GHz and 78.0-94 GHz remain in place. This can be implemented through geographic separation of emitters and RAS facilities. The size of the required protected area around each RAS facility will depend on the number of emitters such that the aggregate interference remains below threshold levels. In addition, the proposed use in the 81-86 GHz band is incompatible with protection of EESS observations at neighboring frequencies. CORF thus recommends that the Commission enable wide guard bands to protect the primary allocation to EESS at 86-92 GHz. (pp.16-19)

IV. Conclusion.

Observations at the frequency bands discussed herein are important for scientific research. CORF generally supports the sharing of frequency allocations where practical, but protection of passive scientific observations, as discussed herein, must be addressed.

Respectfully submitted,

NATIONAL ACADEMY OF SCIENCES'
COMMITTEE ON RADIO FREQUENCIES

By: Ralph J. Cicerone

Ralph J. Cicerone
President, National Academy of Sciences

Direct correspondence to:

CORF
Keck Center of the National Academies
of Sciences, Engineering, and Medicine
500 Fifth Street, NW, Keck 954
Washington, D.C. 20001
(202) 334-3520

January 21 2016
DATE

Appendix

Committee on Radio Frequencies

Members

Jasmeet Judge, *Chair*, University of Florida
Liese van Zee, *Vice Chair*, Indiana University
William Blackwell, MIT Lincoln Laboratory
Todd Gaier, Jet Propulsion Laboratory
Kenneth Jezek, The Ohio State University
David Le Vine, NASA Goddard Space Flight Center
Amy Lovell, Agnes Scott College
Timothy Pearson, California Institute of Technology
Paul Siqueira, University of Massachusetts, Amherst
Gregory Taylor, University of New Mexico
Thomas Wilson, Naval Research Laboratory

Consultants

Michael Davis, SETI Institute (retired)
Darrel Emerson, National Radio Astronomy Observatory (retired)
Paul Feldman, Fletcher, Heald, and Hildreth